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The impact of solar phenomena and correlated geomagnetic, ionospheric and magnetospheric activity on various technologies is indisputable. The most important element in solar-terrestrial forecasting is the understanding of solar events and their impact on the earth's environment. The problems facing forecasters of solar-terrestrial activity were discussed at this Solar-Terrestrial Predictions Workshop held in Ottawa, Canada in May 1992. The results and recommendations of the scientists participating in this Workshop are presented in the main text of this paper. A resolution advocating a simple, reliable spacecraft continuously monitoring the upstream solar wind is given in Appendix A. Finally, a list of some of the events, predictions, and unanticipated phenomena that have posed difficulties to forecasters is documented in Appendix B.

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OVERVIEW OF THE SOLAR-TERRESTRIAL PREDICTIONS WORKSHOP -IV

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ABSTRACT

The impact of solar phenomena and correlated geomagnetic, ionospheric and magnetospheric activity on various technologies is indisputable. The most important element in solar-terrestrial forecasting is the understanding of solar events and their impact on the earth's environment. The problems facing forecasters of solar-terrestrial activity were discussed at this Solar-Terrestrial Predictions Workshop held in Ottawa, Canada in May 1992. The results and recommendations of the scientists participating in this Workshop are presented in the main text of this paper. A resolution advocating a simple, reliable spacecraft continuously monitoring the upstream solar wind is given in Appendix A. Finally, a list of some of the events, predictions, and unanticipated phenomena that have posed difficulties to forecasters is documented in Appendix B.

1. INTRODUCTION

The sophisticated technology on which modern life is dependent is increasingly more vulnerable to the conditions of the space environment surrounding the earth. More people are moving into and working in higher geomagnetic latitudes where major effects of magnetospheric perturbations are frequently observed. Most of these occurrences, and indeed, the largest of these disturbances, are the end result of a chain of events that starts with disruptions on the sun which propagate, in various ways, to the earth where they manifest themselves as perturbations on our geophysical environment. An example of a major disruption on our daily living occurred in March 1989 when an intense geomagnetic storm resulted in a six-hour total electrical power blackout that affected eight million people in Quebec, Canada. Other space and geophysical anomalies reported in association with the solar-terrestrial disturbances of March 1989 included single event upsets on spacecraft, radio communication problems, increased disruption to the corrosion prevention systems on pipelines, and disrupted ground magnetic survey operations (Hruska et al., 1990).

Research on the effects of solar-terrestrial activity is conducted by many groups throughout the world. The scientists strive for a better understanding of the entire cause and effect sequence from the solar phenomena giving rise to an interplanetary disturbance, the propagation of that disturbance through space to the earth, and the effects of the arrival of that disturbance on the earth's geophysical environment. Members of industry, faced with the negative aspects of a major disruption, attempt to mitigate or even prevent these adverse effects. If we had a clear understanding of the complete chain of cause and effect we would be able to predict the onset, magnitude and duration of each disturbance. A reliable forecast of the deterioration of environmental conditions would then permit system operators to take whatever action is necessary to alleviate the adverse effects.

In an effort to bring research activities to the attention of the groups forecasting "Space Weather", and to identify the needs of the forecasters to the research community, a series of Solar-Terrestrial Prediction Workshops have been conducted over the past 13 years. The first workshop was held in Boulder, Colorado, USA in 1979; the second in Meudon, France in 1984, and the third in Leura, Australia in 1989.

2. SOLAR-TERRESTRIAL PREDICTIONS WORKSHOP-IV, OTTAWA, CANADA

Over 150 participants from 17 countries attended the fourth Solar-Terrestrial Predictions Workshop held in Ottawa, Canada in May 1992. This meeting was hosted by the Geological Survey of Canada with assistance of the Department of Communication and the Earth Science Department of Carleton University. Prior to the scientific presentations, a separate meeting of forecasters was held where specific problems were discussed and forecaster requirements were identified as follows:

> The ability to predict or to estimate the delay time between a solar event and a significant response in magnetospheric and terrestrial behavior.
>
> A consensus of models and observations of coronal mass ejections.
>
> An improvement in the understanding in correlations between the solar wind, magnetospheric, ionospheric, and geomagnetic parameters.
>
> A method to continually determine and forecast the boundaries of the auroral oval in real time.

These requirements were presented at the beginning of the workshop so that the participants could focus on the goal of improving the reliability of "Space Weather Forecasts". The forecasters also identified specific periods that have presented problems in predicting various geophysical phenomena. These periods, and the problems each presented, are listed in the Appendix.

Unique to this workshop was a "Users Day" where members of the users community presented their experiences with the effects of solar-terrestrial activity. Although different user groups had different requirements, generally all users requested the following:

> Predictions of the beginning, maximum and end of disturbances. A specific request was the rate of change of geomagnetic variations (dB/dt).
>
> The rapid dissemination of information and data related to large disturbances.
>
> Methods to improve user education on the effects of solar-terrestrial phenomena and ways in which new techniques can be easily tested and evaluated.
>
> A consideration of the geographic diversity in forecasts and the different needs of the users - i.e. forecasts should be "tailored" for the customer's needs.
>
> The development of an ionospheric storm time prediction model.

The participants were divided into four scientific working groups: Solar, Magnetospheric, Geomagnetic, and Ionospheric. The following topics and data bases were identified as necessary for improvements in "Space Weather Forecasting".

2.1 SOLAR WORKING GROUP

The ability to predict the occurrence of solar flares and/or coronal mass ejections.

The ability to identify which solar eruptions will produce copious solar protons at the earth.

The need to improve "medium term" solar predictions. (Short term was considered to be of the order of "days"; long term was considered to be of the order of a "solar cycle".)

Information on the sources of coronal mass ejections

The ability to predict a coronal hole expansion.

A more reliable method to predict the magnitude and time of maximum of the "next" solar cycle.

2.2 MAGNETOSPHERIC WORKING GROUP

The ability to predict when and how interplanetary structures will affect the magnetosphere. The direction of the north/south component of the interplanetary magnetic field in the immediate vicinity of the earth was specifically identified.

The ability to predict substorms.

An improvement in the knowledge of magnetospheric-ionospheric coupling

A method to "nowcast" the state of the magnetosphere

The intercalibration of future solar wind instruments for long term continuity.

The investigation of modern techniques for the overall prediction of the solar-terrestrial environment; e.g. neural networks, artificial intelligence, etc.

2.3 GEOMAGNETIC WORKING GROUP

Identification of the origin of the solar wind, its transport through the interplanetary medium, and its interaction with the magnetosphere.

The geoeffectiveness of solar mass ejections.

Development of new mathematical methods of understanding time series data and related data bases.

An urgent need to develop new geomagnetic indices for measuring higher frequency fluctuations and improved indices describing the local state of geomagnetic activity.

Identification of the relationship between magnetospheric processes and geomagnetic responses to solar events.

2.4 IONOSPHERIC WORKING GROUP

The development of new ionospheric models which will reflect the state of solar and magnetospheric conditions. Separate models for the high latitude ionosphere are also needed. The different characteristics between physical, empirical and statistical models should be delineated.

Continuation of studies of Sporadic E and Spread F layers.

Real-time ionospheric forecasting.

Identification of ionospheric storms, their world-wide and regional characteristics, and their relation to geomagnetic activity.

The development of indices to describe ionospheric conditions.

Although the working groups were divided along traditional lines, many joint meetings between groups were held. It was the consensus of opinion that the lines of distinction between the traditional disciplines have disappeared because there are many different forms of coupling between solar activity and various perturbations in the terrestrial environment. The participants also agreed that a quantum jump in short term geomagnetic forecasting would be realized from the continuous real-time measurements of the solar wind parameters upstream of the earth. A resolution requesting a simple, reliable spacecraft to monitor the upstream solar wind was unanimously adopted by the attendees and is given in Appendix A.

3. EVENTS OF MARCH 1991

The solar activity and the terrestrial perturbations that occurred in March 1991 were extensively discussed throughout the workshop. In many cases this extremely disturbed period was cited as an example of how two episodes of solar activity, neither one of which had all the characteristics indicative of a pending major disturbance at the earth, can give rise to an extremely hostile space environment resulting in a plethora of spacecraft operational anomalies and associated geophysical perturbations.

A major and very impulsive solar flare with soft X-ray onset at 2243 UT occurred on 22 March. This flare was assigned an optical importance 3B and an X-ray magnitude of X9.4 (i.e. equivalent to 9.4×10^{-4} watts meter^{-2}) (Coffey, 1991a, 1991b). The flare was accompanied by strong solar gamma ray and radio emission; it was also the source of energetic solar neutrons detected by a ground-based cosmic ray monitor (Pyle and Simpson, 1991). The identification of a ground-level response to solar neutrons impacting at the top of the atmosphere is indicative of an extremely powerful solar event.

Approximately three hours later, an overlapping sequence of six optically large solar flares combined to give a composite long duration soft X-ray event of magnitude M6.8 (i.e.

equivalent to 6.8 x 10^{-5} watts $meter^{-2}$). This sequence of solar activity was not associated with strong radio emission nor did any of the individual solar flares have the X-ray emission magnitude of the X9.4 flare of the previous day. The onset of the solar particle event which continued for eight days occurred a few hours later.

Figure 1 illustrates the solar and near-earth space environment on 22-23 March 1991. The 1-8 Å soft solar X-ray flux as measured by the GOES-7 synchronous orbit spacecraft is shown on the top of the figure; the events late on the 22nd and early on the 23rd are clearly evident. The integral proton flux for four energies, also measured on GOES-7, is illustrated in the center of the figure. The solar proton event with onset between 7 and 8 UT on 23 March is clearly visible.

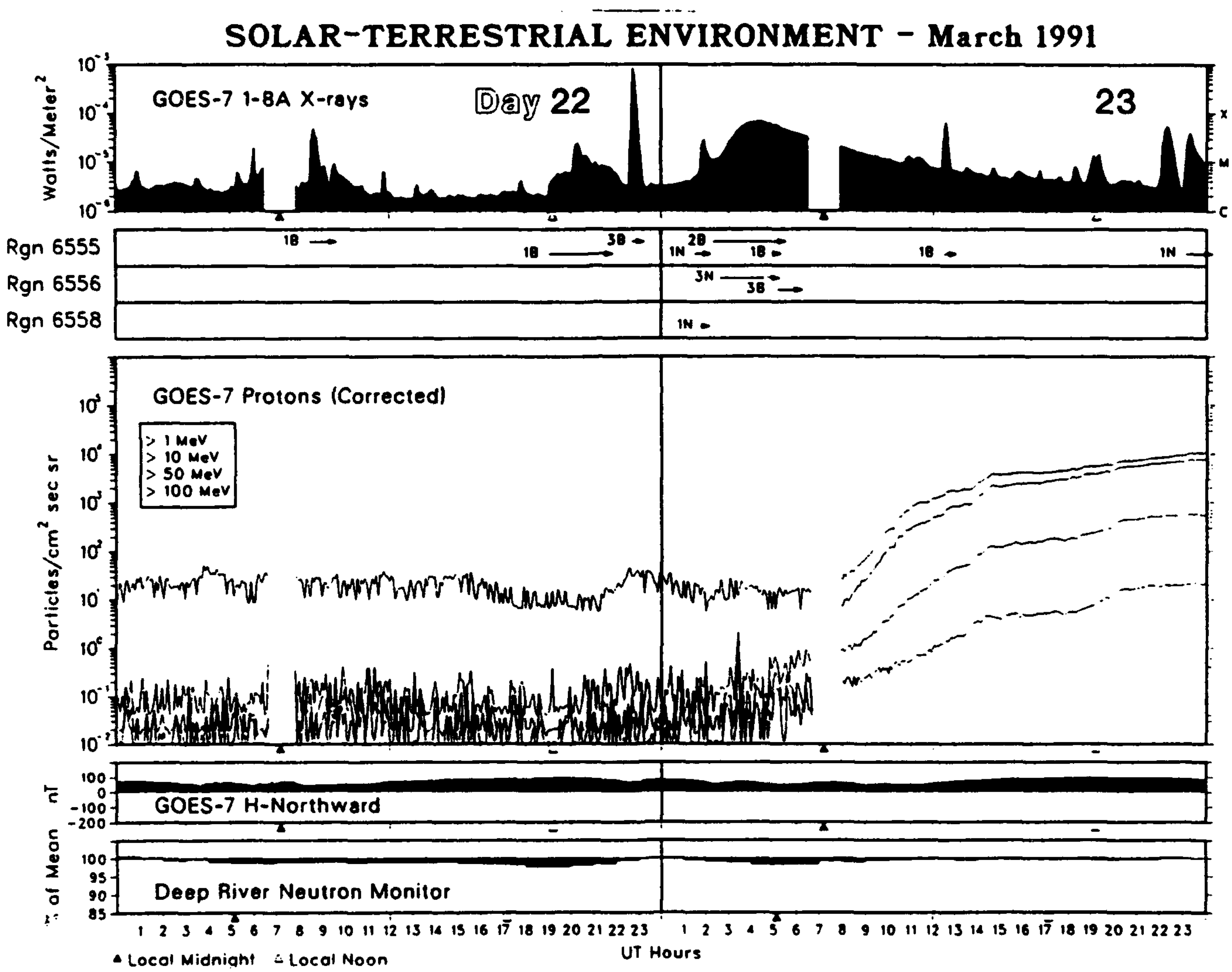

Figure 1. Illustration of the solar and terrestrial environment on 22-23 March 1991. The 1-8 Å soft solar X-ray flux as measured by the GOES-7 synchronous orbit spacecraft is at the top. The associated solar flares are indicated immediately below. Four selected integral proton flux energies from the GOES-7 spacecraft are shown in the center panel. The GOES-7 magnetometer is shown next followed by the cosmic radiation intensity, as measured by the neutron monitor at Deep River, Canada.

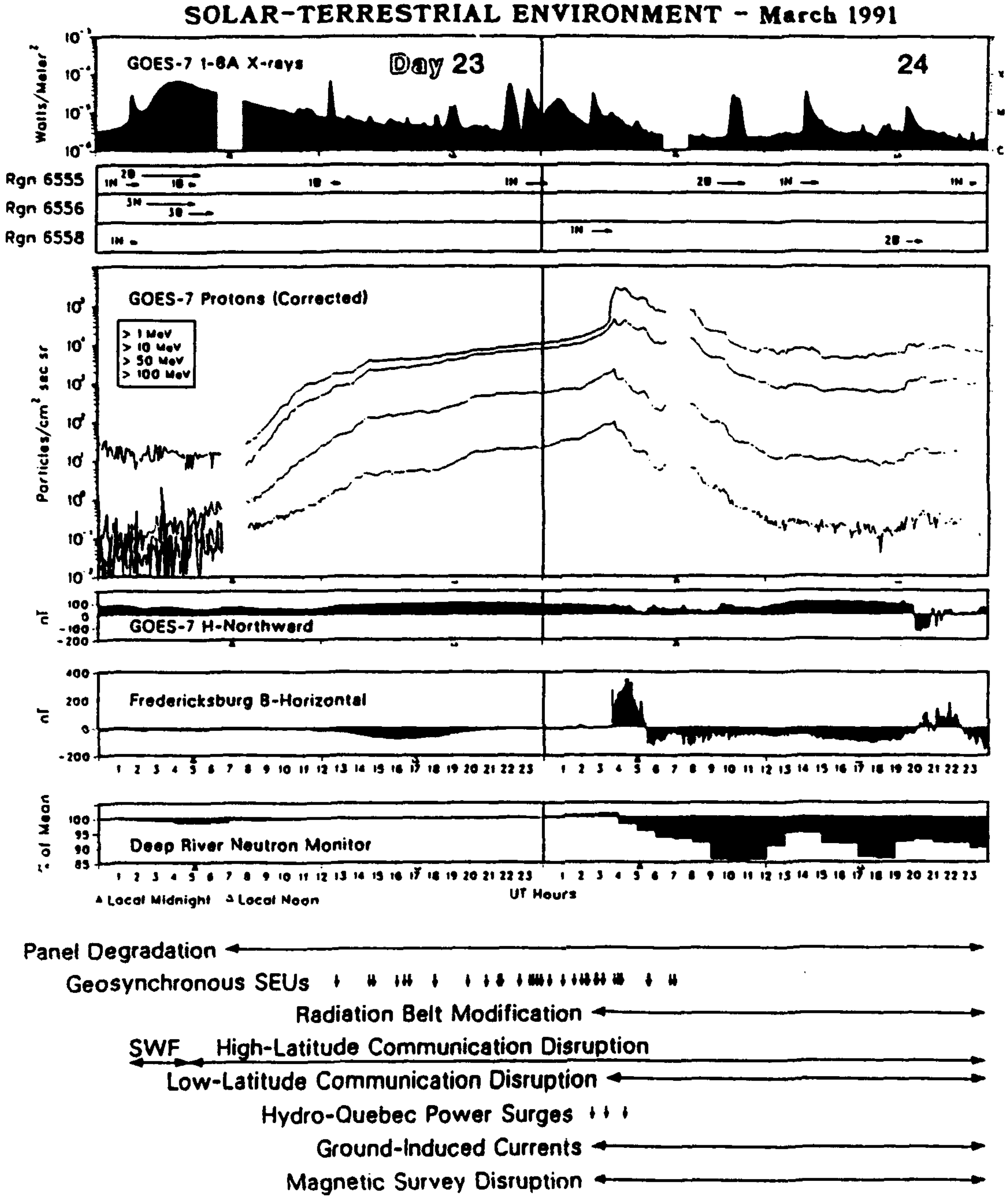

Figure 2. Illustration of the solar and terrestrial environment on 23-24 March 1991. Top: The 1-8 Å soft solar X-ray flux as measured by the GOES-7 synchronous orbit spacecraft. Associated solar flares are indicated immediately below. Four selected integral proton flux energies from the GOES-7 spacecraft are shown in the center panel. The GOES-7 magnetometer is shown next followed by the earth's magnetic field variations observed at Fredericksburg, Virginia. Below this is the cosmic radiation intensity, as measured by the neutron monitor at Deep River, Canada. A summary of the spacecraft and other operational anomalies and effects are listed at the bottom with the arrows indicating the times of degraded operation.

Figure 2 illustrates the solar, near-earth space and terrestrial environments on 23 and 24 March. For continuity, the top four panels for 23 March are repeated in the same sequence as Figure 1. The solar particle flux as measured on GOES-7 steadily increases from the onset on 23 March until early 24 March when there is an abrupt and rapid enhancement. This increased intensity around 0400 UT on 24 March is associated with the arrival of a rapidly moving interplanetary shock structure generated by the solar flare activity on 22/23 March. A summary of spacecraft and other operational anomalies and effects are listed at the bottom of this figure.

This combination - an enhanced flux of solar protons in the interplanetary medium together with a very powerful interplanetary shock sequence - results in an acceleration of the initially injected solar flare generated proton flux to higher energies than were present in the initial solar proton flux. The rapidly changing geophysical environment in late March 1991 was the result of this series of solar flares and interplanetary magnetic shock structures. This sequence of activity produced the second largest proton fluence above 10 MeV that has been measured at the earth thus far this solar cycle. The magnitude of this entire disturbance - from the particle event to the geomagnetic field perturbations - was not predictable by present methods. Although these spatial and geophysical disturbances were the result of solar activity primarily from NOAA solar region number 6555, major solar activity from regions in close proximity to region 6555 makes it difficult to assign a unique identification of specific solar activity with specific interplanetary and terrestrial phenomena. It was extremely unfortunate that there were no coronal mass ejection measurements nor interplanetary plasma data during the critical times of this event as these data would have greatly assisted in analyses of these major perturbations. Details on the 22-24 March 1991 activity are given by Shea et al. (1992).

4. SUMMARY

The workshop participants agreed that a systematic presentation of solar, interplanetary and terrestrial data together with associated operational anomalies for the major events of this and previous solar cycles would be helpful in identifying the similarities and differences between events. Also beneficial to the scientific community would be the identification of some events where forecasters experienced major difficulties in making reliable forecasts; this we have done in Appendix B. These events should be studied in detail to ascertain if other observables, perhaps not presently available in real-time data, might have improved the forecasts. One of the sessions at the next Workshop could be studies of these "problem events".

This fourth Solar-Terrestrial Predictions Workshop was an extremely successful meeting of scientific researchers, forecasters, and industrial users of forecasts of "Space Weather". As with the previous three workshops, the scientific papers were all refereed and are published in these three volumes. The next workshop is expected to be held in Japan around 1995.

5. REFERENCES

Coffey, H.E., (Ed.), Solar-Geophysical Data, No. 565, Part II, National Geophysical Data Center, NOAA, Boulder, Colorado, pp. 26-27, September 1991a.

Coffey, H.E., (Ed.), Solar-Geophysical Data, No. 565, Part II, National Geophysical Data Center, NOAA, Boulder, Colorado, pp. 158, September 1991b.

Hruska, J., R. Coles, H.L. Lam, and G. Jansen van Beek, The Major Magnetic Storm of 13-14 March 1989: Its Character in Canada and some Effects, in Solar-Terrestrial Predictions: Proceedings of a Workshop at Leura, Australia, 2, Edited by R.J. Thompson, D.G. Cole, P.J. Wilkinson, M.A. Shea, D. Smart, and G. Heckman, U.S. Department of Commerce, NOAA, ERL, Boulder, Colorado, 429-442, 1990.

Pyle, K.R., and J.A. Simpson, Observation of a Direct Solar Neutron Event on 22 March 1991 with the Haleakala, Hawaii, Neutron Monitor, in 22nd International Cosmic Ray Conference Contributed Papers, Dublin, Ireland, 53-56, 1991.

Shea, M.A., D.F. Smart, J.H. Allen, and D.C. Wilkinson, Spacecraft Problems in Association with Episodes of Intense Solar Activity and Related Terrestrial Phenomena During March 1991, *IEEE Trans. on Nucl. Sci.*, *39*, 1754-1760, 1992.

APPENDIX A

RESOLUTION ON SOLAR WIND MONITORING SPACECRAFT

The following resolution was unanimously adopted by the attendees at this Workshop:

Because continuous real-time measurements of the solar wind parameters upstream of the Earth provide direct knowledge of the energy input into the magnetospheric/ionospheric environments and this energy input directly impacts spacecraft health and data reliability, power, pipeline and communications integrity, and geophysical exploration and other data quality, the Fourth Solar- Terrestrial Predictions Workshop participants (150 people representing 17 countries) call upon the worldwide scientific research and applications community to provide as quickly as possible a simple, reliable spacecraft to monitor the upstream solar wind. It is suggested that a pooling of resources and talents from many affected national agencies could make the costs of providing such a spacecraft modest to each agency. We urge a solution to this outstanding problem that is kept simple and highly focussed upon the minimum requirements for real-time plasma and interplanetary magnetic field quantities near the upstream Lagrangian (L_1) point.

APPENDIX B

REGIONAL WARNING CENTER (RWC) DIFFICULT FORECASTS

Appendix B is a list of difficult forecast situations experienced by the RWCs. These represent periods when forecasters had problems predicting the geoeffectiveness of solar activity. There are three sections to this list, one for each range of forecast provided by the RWCs, namely, short-term (days in advance), mid-term (weeks to a month in advance), and long-term (solar cycle length periods).

The table lists the date when the forecast was issued to users, the type of forecast (flare, geomagnetic, or energetic particle prediction), the day the forecast activity was expected to occur, what levels were forecast for that day, what actually occurred during the forecast period, and the forecaster comments explaining why they felt the forecast was difficult.

APPENDIX B

RWC Difficult Forecasts

Short-term (days in advance)

Forecast Issued	Forecast Type	Forecast Day	Forecast	Observed	Comments
01 Jan 1988	Flare	02 Jan 1988	Not predicted (1% chance)	X1/3B Flare on 02 Jan 1988 at 2135UT located at (S34W24)	Slowly decaying region (SESC 4912) had been producing only small flares. Observations limited by bad weather.
26 Jan 1989	Flare	27 Jan 1989	1% chance for X flare.	X1/2B flare on 27 Jan 1989 at 1917UT located at (S17E14)	No identifiable precursor.
22 Dec 1990	Flare	23 Dec 1990	10% chance for X flare.	X1 flare on 23 Dec 1990 at 1001UT located at (N11W68)	Region 6412 produced this flare and had been a very active region, producing 42 C - class events and 6 M-class events but forecasters did not expect major activity.
23 Dec 1990	Flare	24 Dec 1990	10% chance for X flare	X1 flare on 24 Dec 1990 at 1546UT located at (N10W80)	Forecasters did not expect Region 6412 to produce another major event so quickly after the X1 on 23 Dec.
24 Feb 1991	Flare	25 Feb 1991	5% chance for X flare	X1/2N flare on 25 Feb 1991 at 0822UT located at (S11W90)	Region 6497 that produced the flare showed signs of decaying earlier.

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Forecast Issued	Forecast Type	Forecast Day	Forecast	Observed	Comments
02 Apr 1988	Geomagnetic	04 Apr 1988	Unsettled conditions	Major storm, Ap = 78	Source unknown.
08 May 1992	Geomagnetic	10 May 1992	Active conditions	Severe storm, Ap = 179	Based on disappearing filament, timing off by a few hours and activity more than expected.
22 Aug 1992	Geomagnetic	23 Aug 1992	Unsettled conditions	Major storm, Ap = 73	Some prior M class flares and disappearing filaments, but none were impressive.
25 Mar 1988	Solar energetic particle	26 Mar 1988	2% chance	Event reached 58pfu @>10 MeV	Parent activity probably was a C4 flare / eruptive prominence at N21 W90 with type II and IV radio sweeps
23 Sep 1993	Solar energetic particle	25 Sep 1993	Not predicted (1% chance)	Small but high energy event, measurable proton fluxes above 100 MeV	Although fluxes did not reach event threshold, this increase was not predicted and no precursors were found.

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Mid-term (27 days in advance)

Forecast Issued	Forecast Type	Forecast Day	Forecast	Observed	Comments
07 Jan 1992	Geomagnetic	26 Jan 1992	Unsettled conditions	Quiet, Ap = 7	Recurrence activity during five previous solar rotations was at higher levels.
14 Jan 1992	Geomagnetic	03 Feb 1992	Unsettled conditions	Major storm, Ap = 92	Not recurrent activity. Probable source was an M4/2b and/or four other M - class flares observed on 30 Jan 1992. There were type II and type IV radio emissions detected. Also, there was a coronal hole reported on its first rotation.
10 Mar 1992	Geomagnetic	26 Mar 1992	Active conditions	Unsettled, Ap = 12	Persistent coronal hole expected to keep field active.
14 Apr 1992	Geomagnetic	10 May 1992	Unsettled to active conditions	Severe storm, Ap = 179	Not recurrent activity. Probable source was an eruptive prominence / Hyder flare on 07 May 1992 and/or an M7/4B flare on 08 May 1992.
09 Jun 1992	Geomagnetic	06 Jul 1992	Unsettled to active conditions	Quiet	Expected recurrent activity to continue another solar rotation.
28 Jul 1992	Geomagnetic	23 Aug 1992	Unsettled conditions	Major storm, Ap = 73	The effect of a series of M - class flare on the 20th and 21st of Aug 1992 from Region 7560. On 20 Aug ,an M2/1B at 0905UT, an M4/1B at 1435UT, an M1/1B at 1727UT, and an M3/1B at 2035UT were observed. On the 21 Aug, there were an M1/1B at 0016UT, an M1/1F at 1108UT, and an M1/1N at 1203UT were observed.

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Forecast Issued	Forecast Type	Forecast Day	Forecast	Observed	Comments
08 Dec 1992	Geomagnetic	29 Dec 1992	Unsettled conditions	Minor storm, Ap = 42	Unexpected emergence of a coronal hole appears to be source.
05 Jan 1993	Geomagnetic	31 Jan 1993	Unsettled conditions	Major storm, Ap = 59	Most likely source was a negative polarity coronal hole.
02 Mar 1993	Geomagnetic	24 Mar 1993	Quiet conditions	Major storm, Ap = 50	Source most likely a disappearing filament / coronal mass ejection, tough to forecast one rotation in advance.
05 Jun 1990	10.7cm flux	17 Jun 1990	F10 = 270	F10 = 187	Activity declined faster than expected. The peak flux value occurred on 02 July 90 at 267 flux units.
28 Jul 1992	10.7cm flux	09 Aug 1992	F10 = 160	F10 = 137	The expected regions returned, but the peak flux value occurred later, on 20 August 92 at 156 flux units.
09 Mar 1993	10.7cm flux	03 Apr 1993	F10 = 155	F10 = 117	The expected regions returned but not nearly as active as anticipated. The peak flux value occurred on 08 April 92 at 143 flux units.
30 Mar 1993	10.7cm flux	20 Apr 1993	F10 = 150	F10 = 119	Regions returned , but not active. The flux reached a low of 88 on 15 April 92.

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Long-term (years in advance)

Forecast Issued	Forecast Type	Forecast	Result	Comments
1986	Solar cycle 22	Average solar cycle	Solar cycle 22 was the third largest on record.	A wide spectrum of forecasts using variety of methods gave conflicting results.
1988	Solar maximum	Comparable to solar cycle 19 (largest on record).	Peak smooth sunspot number for Solar Cycle 22 was 158 compared with 201 for cycle 19.	The rapid rise of the smooth sunspot number and 10.7cm radio flux for cycle 22 was the fastest on record leading to expectations that this trend would continue into 1990.
1992	Solar minimum.	Expect a longer than average cycle.	Solar Cycle 22 may be one of the shortest cycles.	Outputs from regression models gave indications for a long decay of the solar cycle.
1993	Solar cycle 23	Larger than average cycle.	Unknown at this time.	Even-odd bi-modality paradigm would indicate Solar Cycle 23 will be larger than cycle 22.

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